VARIOUS APPLICATIONS OF MULTICOLOUR PHOTOMETRY AND RADIAL VELOCITY DATA FOR MULTIMODE δ SCUTI STARS

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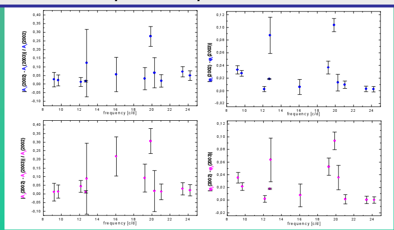
*In addition to revealing spherical harmonic degrees, ℓ, of excited modes, amplitude and pulsation phases from **multicolour photometry** and **radial velocity** data yield valuable information about the star. This includes constraints on atmospheric parameters and subphotospheric convection. Multiperiodic pulsators are of particular interest because each mode yields independent constraints. We present an analysis of data on twelve modes observed in FG Vir star.*

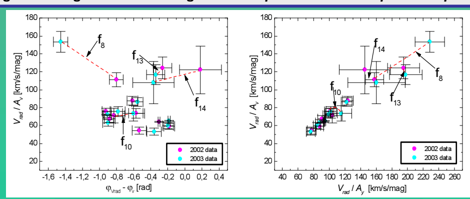
FG Vir is the most multimodal δ Scuti pulsator.
Total number of modes detected is 48 ! (Breger et al. 2004).
For twelve frequencies we have two-colour Strömgren photometry (v,y) and radial velocity data.

Mean parameters of FG Vir:
$\log T_{\rm eff}=3.875 \pm 0.009$, $\log g=4.0 \pm 0.1 \Rightarrow M=1.85 \pm 0.1\, M_\odot$
(Breger et al. 1999)
[m/H]=0.0 (Z=0.02) (Mittermayer & Weiss 2003)

Differences in amplitudes and phases between 2002 and 2003.



Diagnostic diagrams for ℓ's using combined photometric and spectroscopic data.



Using non-contemporaneous data unsafe !

A METHOD OF INFERRING ℓ

Equations for complex monochromatic flux amplitudes.

$$\mathcal{D}_\ell^\lambda(\tilde\varepsilon f) + \mathcal{E}_\ell^\lambda \tilde\varepsilon = A^\lambda, \qquad (1)$$

where

$$\tilde\varepsilon = \varepsilon Y_\ell^m(i,0),$$

$$\mathcal{D}_\ell^\lambda = \frac{1}{4} b_\ell^\lambda \frac{\partial \log(\mathcal{F}_\lambda |b_\ell^\lambda|)}{\partial \log T_{\rm eff}},$$

$$\mathcal{E}_\ell^\lambda = b_\ell^\lambda \left[(2+\ell)(1-\ell) - \left(\frac{\omega^2 R^3}{GM} + 2\right)\frac{\partial \log(\mathcal{F}_\lambda |b_\ell^\lambda|)}{\partial \log g}\right].$$

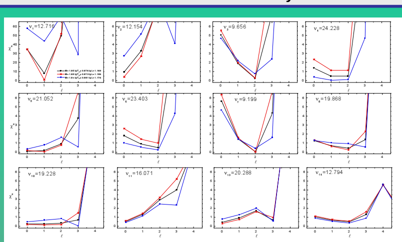
Equation for complex radial velocity amplitude (the first moment, M_1^λ).

$$i\omega R\left(u_\ell^\lambda + \frac{GM v_\ell^\lambda}{R^3\omega^2}\right)\tilde\varepsilon = \mathcal{M}_1^\lambda. \qquad (2)$$

Each passband, λ, yields r.h.s. of equations (1) .
Measurements of radial velocity yield r.h.s. of equation (2).
With data from two pasbands we have three complex linear equations for two complex unknowns: $\tilde\varepsilon$ and $(\tilde\varepsilon f)$.
The equations are solved by LS method for specified ℓ.
The ℓ determination is based on the behavior of minima of $\chi^2(\ell)$.
The inferred f values are of interest as constraints on stellar convection models (Daszyńska-Daszkiewicz, Dziembowski, Pamyatnykh 2003).

Mean atmospheric parameters, Teff, log g and [m/H], enter through D_ℓ^λ, E_ℓ^λ and the disc averaging factors.

ε - complex parameter fixing mode amplitude and phase, i - inclination angle, b_ℓ^λ, u_ℓ^λ, v_ℓ^λ - limb-darkening-weighted disc averaging factors
$F_\lambda (T_{\rm eff}, g)$ - monochromatic flux from static atmosphere models. We use tabular data of Kurucz (1993) as well as data from other sources.
f - complex parameter from nonadiabatic calculations, (εf) is the relative bolometric amplitude
For δ Scuti stars we have no reliable calculations of f. We rely on observational determinations of f together with ℓ .

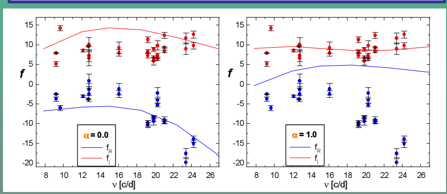


Possible identifications of ℓ ($\chi^2(\ell)<1.6$) within the accepted $T_{\rm eff}$ range.

Frequency in [c/d]	our identification from phot.& spec.	Breger et al. (1995)	Viscum et al. (1998)	Breger et al. (1999)
ν_1= 12.7164	$\ell=1$	$\ell=0$	$\ell=1$	$\ell=1$
ν_2= 12.1541	$\ell=0$	$\ell=2$	$\ell=0$	$\ell=0$
ν_3= 9.6563	$\ell=2$	$\ell=2$	$\ell=2$	$\ell=1,2$
ν_4= 24.2280	$\ell=2,1,0$	$\ell=0$	$\ell=1$	$\ell=1,2$
ν_5= 21.0515	$\ell=1,0,2$	$\ell=1$	$\ell=2$	$\ell=2$
ν_6= 23.4033	$\ell=2,1,0$	$\ell=2$	$\ell=0$	$\ell=0,1$
ν_7= 9.1991	$\ell=2,1$	$\ell=2$	$\ell=2$	$\ell=2$
ν_8= 19.8676	$\ell=2,1,0$	$\ell=2$	$\ell=2$	$\ell=2$

We are less optimistic than our predecessors: our unique identifications are only for the three highest peaks. Modes with $\ell > 3$ are excluded in all twelve cases.

Comparison of empirical values of f with theoretical values calculated with a naive model of pulsation-convection interaction (MLT, convective flux freezing). f should be ℓ-independent.



USING ATMOSPHERIC MODELS FROM DIFFERENT SOURCES

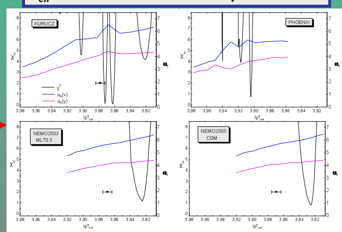
- identifications of ℓ unchanged
- the values of f are similar
- but χ^2 >>1

Problem 1: Acceptable values of χ^2 found outside the acceptable $T_{\rm eff}$ range, see

Problem 2: bad shape of $\chi^2(T_{\rm eff})$ due to non-smooth derivatives

$$\alpha_T = \frac{\partial \log \mathcal{F}_\lambda}{\partial \log T_{\rm eff}}$$

$T_{\rm eff}$ from mean colours and the pulsation data



CONCLUSIONS

- ℓ identification of excited modes without a priori knowledge of f is possible but only for modes with sufficiently high amplitudes
- inferred values of f are crudely consistent with models calculated assuming inefficient convection ($\alpha \approx 0.0$)
- effective temperature may be constrained with pulsational data but improvements in atmospheric models are needed

References:
Breger M., Pamyatnykh A. A., Pikall H., Garrido R., 1999, A&A 341, 151
Breger M. et al. 2004, A&A 419, 696
Claret A., 2003, private communication
Daszynska-Daszkiewicz J., Dziembowski W. A., Pamyatnykh A. A. 2003, A&A 407,999
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